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(54) Title: NICKEL DIIMINE CATALYSTS WITH METHYLALUMOXANE AS COCATALYST, METHOD OF POLYMERIZATION OF OLEFINS THEREWITH AND POLYMERS PRODUCED

(57) Abstract

Tetrasubstituted diphenyl diimine nickel complexes further comprising e.g. ACAC ligands and their fluorinated analogs as additional ligands are used in conjunction with methylalumoxane and a support to polymerize alpha olefins or copolymerize plural alpha olefins in the slurry phase.

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NICKEL DIIMINE CATALYSTS WITH METHYLALUMOXANE AS COCATALYST, METHOD OF POLYMERIZATION
OF OLEFINS THEREWITH AND POLYMERS PRODUCED

BACKGROUND

This invention relates to homopolymerization of mono-1-olefin
monomers, such as ethylene and propylene, and copolymerization of a mono-1-olefin
5   monomers, such as ethylene and propylene, with at least one higher alpha-olefin
comonomer.

It is well known that mono-1-olefins, such as ethylene and propylene,
can be polymerized with catalyst systems employing transition metals such as
titanium, vanadium, chromium, nickel and/or other metals, either unsupported or on a
10   support such as alumina, silica, titania, and other refractory metals. Supported
polymerization catalyst systems frequently are used with a cocatalyst, such as alkyl
boron and/or alkyl aluminum compounds. Organometallic catalyst systems, i.e.,
Ziegler-Natta-type catalyst systems usually are unsupported and frequently are used
with a cocatalyst, such as methylaluminoxane.

15   It is also well-known that, while no polymer production process is
easy, slurry, or loop, polymerization processes are relatively much more commercially
desirable than other polymerization processes. Furthermore, the type of
polymerization process used can have an effect on the resultant polymer. For
example, higher reactor temperatures can result in low catalyst activity and
20   productivity, as well as a lower molecular weight polymer product. Higher reactor
pressures also can decrease the amount of desirable branching in the resultant
polymer.

Most polymer products made in slurry processes, especially those
polymer products made using supported chromium catalyst systems, have a broader
25   molecular weight distribution and, therefore, the polymer product is much easier to
process into a final product. Polymers made by other processes, such as, for
example, higher temperature and/or higher pressure solution processes, can produce
polymers having a narrow molecular weight distribution; these polymers can be much
more difficult to process into an article of manufacture.

30   Unfortunately, many homogeneous organometallic catalyst systems
have low activity, high consumption of very costly cocatalysts, like
methylaluminoxane (MAO), and can produce low molecular weight polymers with a

- 2 -

narrow molecular weight distribution. Furthermore, even though MAO can be
necessary to produce a polymer with desired characteristics, an excess of MAO can
result in decreased catalyst system activity. Additionally, these types of
homogeneous catalyst systems preferably are used only in solution or gas phase
5   polymerization processes.

SUMMARY OF THE INVENTION

The present invention provides novel catalyst systems useful for
polymerization, for example, catalyst systems which are relatively simple to make,
have increased activity and increased productivity.

10   The invention also provides catalyst systems which have reduced
cocatalyst consumption, and/or which provide an improved polymerization process.

The invention further provides homopolymers of mono-1-olefins and
copolymers of at least two different mono-1-olefin(s) that can be processed easily, as
indicated by increased branching and a broad molecular weight distribution, and/or
15   which have an increased molecular weight.

In accordance with this invention heterogeneous catalyst systems
comprising diimine nickel complexes which further comprise additional ligands
selected from the group consisting of α-deprotonated-β-diketones, α-deprotonated-β-
ketoesters, halogens and mixtures thereof having a formula selected from the group
20   consisting of $Ni(NCR'C_6R_2H_3)_2(Y_2C_3R''_2X)_2$ and $Ni(NCR'C_6R_2H_3)_2(Y_2C_3R''_2X)Z$ and
methylaluminoxane are provided. Processes to make these catalyst systems also are
provided.

In accordance with another embodiment of this invention, slurry
polymerization processes comprising contacting ethylene, and optionally one or more
25   higher alpha-olefins, in a reaction zone with heterogeneous catalyst systems
comprising diimine nickel complexes which further comprise additional ligands
selected from the group consisting of α-deprotonated-β-diketones, α-deprotonated-β-
ketoesters, halogens and mixtures thereof in the presence of methylaluminoxane are
provided.

30   In accordance with this invention heterogeneous catalyst systems
consisting essentially of diimine nickel complexes which further comprise additional
ligands selected from the group consisting of α-deprotonated-β-diketones, α-

- 3 -

deprotonated-β-ketoesters, halogens and mixtures thereof and methylaluminoxane are provided. Processes to make these catalyst systems also are provided.

In accordance with another embodiment of this invention, slurry polymerization processes consisting essentially of contacting ethylene, and optionally

5   one or more higher alpha-olefins, in a reaction zone with heterogeneous catalyst systems comprising diimine nickel complexes which further comprise additional ligands selected from the group consisting of α-deprotonated-β-diketones, α-deprotonated-β-ketoesters, halogens and mixtures thereof in the presence of methylaluminoxane are provided.

10   By use of the term "consisting essentially of" it is intended that the catalyst systems do not contain any further component which would adversely affect the desired properties imparted to the catalyst systems by the components recited after this expression, and that the process of the invention does not contain any further steps which would have an adverse affect on the desired object of the invention.

15   In accordance with yet another embodiment of this invention, compositions comprising homopolymers of ethylene and copolymers of ethylene and one or more higher alpha-olefins which can be characterized as having high molecular weight, increased branching and a broad molecular weight distribution, are provided.

20   DESCRIPTION OF THE PREFERRED EMBODIMENTS
Catalyst Systems

Catalyst systems of this invention can be characterized as diimine nickel complexes comprising additional ligands selected from the group consisting of β-diketonates, halogens and mixtures thereof having a formula selected from the

25   group consisting of $Ni(NCR'C_6R_2H_3)_2(Y_2C_3R''_2X)_2$ and $Ni(NCR'C_6R_2H_3)_2(Y_2C_3R''_2X)Z$ and also represented by general structural formulas as shown below in Compounds I and II,
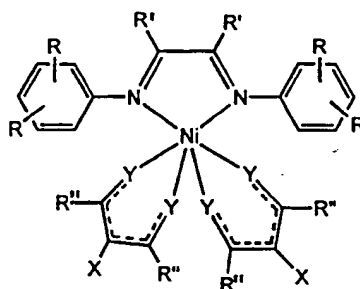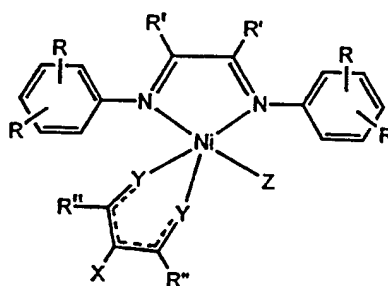
Compound I

R' R'
R
N N
R' R
Ni
Y Y
R" Y Y R"
X R" R" X

Compound II

R' R'
R
N N
R' R
Ni
Y Z
R" Y
X R"

wherein R can be the same or different and is selected from the group consisting of branched or linear alkyl or aromatic groups having from about 1 to about 10, preferably from about 1 to about 8, carbon atoms per alkyl group and R can be in any position on the aromatic ring; and

R' can be the same or different and is selected from the group consisting of hydrogen and linear, branched, cyclic, bridging, aromatic, and/or aliphatic hydrocarbons, having from about 1 to about 70, preferably from about 1 to about 20, carbon atoms per radical group.

R substituents on the aromatic rings of the diimine nickel complex can be the same or different, and are selected from the group consisting of branched or linear alkyl (aliphatic) or aromatic groups having from about 1 to about 10, preferably from about 1 to about 8, carbon atoms per alkyl group. Although hydrogen can be used, hydrogen can inhibit synthesis of the ligand. R groups having more than about 8 carbon atoms per group can result in a catalyst system with lower activity and/or productivity. While not wishing to be bound by theory, it is believed that larger substituent groups can cause steric hindrance in the catalyst system, thereby which can decrease catalyst system activity and/or productivity and/or ease of synthesis of the catalyst. Exemplary alkyl substituents are selected from the group

- 5 -

consisting of methyl, ethyl, propyl, isopropyl, butyl, isobutyl, tert-butyl, benzyl, phenyl groups, and mixtures of two or more thereof. Preferably, the R substituent is an electron-donating species, selected from the group consisting of linear or branched aliphatic groups having from about 1 to about 5 carbon atoms per group. Most

5   preferably, the R groups are both the same and are selected from the group consisting of methyl and isopropyl, due to commercial availability and ease of synthesis of the ligand.

The R group can be in any position, i.e., from 2 to 6, on the aromatic ring. Preferably, the R group, which can be the same or different, is either in the 2

10   or 6 position, due to ease of synthesis. Most preferably, for best catalytic activity and productivity, both R groups are the same and are in the 2 and 6 positions on the aromatic ring.

R' substituents can be the same or different and are selected from the group consisting of hydrogen and branched, linear, cyclic, aromatic or aliphatic

15   radicals having from about 1 to about 70 carbon atoms per radical. Further, the R' substituents can be linked, or joined, across the carbon-carbon bridge between the two nitrogen atoms. While not wishing to be bound by theory, it is believed that radicals having more than 70 carbon atoms can add to the steric hindrance of the catalyst systems and hinder catalyst synthesis and/or activity and productivity. Preferably, the

20   R' substituent group is selected from the group consisting of hydrogen and branched, linear, cyclic, aromatic or aliphatic radicals having from about 1 to about 20 carbon atoms per radical, due to commercial availability and ease of synthesis of the ligand. Most preferably, the R' substituent groups are the same or a link across the carbon-carbon bridge between the nitrogen atoms, and the R' substituent is selected from the

25   group consisting of hydrogen and branched, linear, cyclic, aromatic or aliphatic radicals having from about 1 to about 12 carbon atoms per radical, for the reasons given above. Exemplary R' substituents include, but are not limited to, hydrogen, methyl, ethyl, propyl, phenyl, taken together acenaphthyl or cyclobutadienyl. Preferably, the R' substituents are identical and are selected from the group consisting

30   of hydrogen, methyl and acenaphthyl for best resultant catalyst system activity and productivity.

- 6 -

R"CYCXCYR" substituents, or ligands, on the diimine nickel complex can be the same or different and are selected from the group consisting of α-deprotonated-β-diketones, α-deprotonated-β-ketoesters, halogens and mixtures thereof. The α-deprotonated-β-diketones and α-deprotonated-β-ketoesters can be derived from

5   β-diketone and β-ketoester ligand precursors. Exemplary ligands precursors include, but are not limited to, compounds selected from the group consisting of 2,4-pentane-dione, 1,1,1,5,5,5-hexafluoro-2,4-pentanedione, allylacetonacetate, benzoylacetonate, benzoyl-1,1,1-trifluoroacetone, 1,1,1-trifluoro-2,4-pentanedione, 1-chloro-1,1-difluoro-acetylacetone methyl-4,4,4-trifluoroacetoacetate, 1,1,1-trifluoro-5,5-dimethyl-2,4-

10   pentanedione, ethyl α-methyl-4,4,4-trifluoroacetoacetate, 4,4,4-trifluoro-1-(2-furyl)-1,3-butanedione, and 2,2-dimethyl-6,6,7,7,8,8,8-heptafluoro-3,5-octanedione. Preferably, ligand precursors are selected from the group consisting of 2,4-pentane-dione, 1,1,1,5,5,5-hexafluoro-2,4-pentanedione, 1,1,1-trifluoro-2,4-pentanedione, 1-chloro-1,1-difluoroacetylacetone, methyltrifluoroacetoacetate, 1,1,1-trifluoro-5,5-

15   dimethyl-2,4-pentanedione, and ethyl α-methyl-4,4,4-trifluoroacetoacetate. Most preferably, ligands include, but are not limited to 2,4-pentanedione, 1,1,1,5,5,5-hexafluoro-2,4-pentanedione, 1,1,1-trifluoro-2,4-pentanedione, 1-chloro-1,1-difluoro-acetylacetone, and 1,1,1-trifluoro-5,5-dimethyl-2,4-pentanedione for best catalyst system activity as well as best polymer product properties.

20   R" and X can be the same or different and are selected from the group consisting of hydrogen and linear, branched, cyclic, bridging aromatic and aliphatic hydrocarbon and mixtures of any two or more of these radicals having from about 1 to about 70 carbon atoms per radical group.

        The group Z, i.e., halogen, of the diimine nickel complex is selected

25   from the group consisting of fluorine, chlorine, bromine and/or iodine. Preferably, the halogen is selected from the group consisting of chlorine and/or bromine for high catalyst activity and productivity. Most preferably, the halogen is chlorine for best catalyst system activity and productivity.

        Y is independently selected from the group consisting of oxygen,

30   sulfur and selenium.

        The diimine nickel complex catalyst system disclosed in this application can be prepared by any method known in the art. For example,

approximate molar equivalents of a diimine ligand and a nickel compound can be
contacted in the presence of any compound that can dissolve both the diimine ligand
and nickel compound, either partially or completely. The contacting conditions can
be any conditions suitable to effect the formation of a diimine nickel complex.

5   Preferably, for best product results, the diimine ligand/nickel complex mixture is
contacted at room temperature under a dry atmosphere for any amount of time
sufficient to form the diimine nickel complex. Completion of the formation of the
diimine nickel complex can be evidenced by a color change. Generally, contacting
times of about 8, and preferably 12 hours are sufficient. Usually, as a result of the

10   preparation procedure, the resultant diimine nickel complex will comprise from about
3 to about 20, preferably from about 5 to about 15, weight percent nickel, based on
the total mass of the diimine nickel complex. The presence of oxygen is not thought
to be detrimental to this aspect of the preparation procedure.

In general, diimine ligands are contacted with a nickel β-diketonate or

15   nickel β-diketonate halide to form diimine nickel complexes. Typical syntheses of
nickel complexes related to those described in this invention can be found in Dieck,
H., Svboda, M., and Greiser, T., <u>Z. Naturforsch B: Anorg. Chem. Organ. Chem.</u>,
Vol. 36b, pp. 823-832 (1981), herein incorporated by reference. Usually, for ease of
catalyst system preparation, the diimine ligand is prepared first. The catalyst

20   preparation procedure can vary, depending on the substituents on the diimine ligand.
For example, to prepare a specific diimine ligand, wherein R' is hydrogen, a three-
component mixture is prepared. A two-fold molar excess of aniline, containing the
desired R substituents ($R_nC_6H_{(7-n)}N$, wherein n = 1,2), is contacted with a dialdehyde,
such as, for example, glyoxal (CHOCHO), in the presence of a compound capable of

25   being a solvent for both organic and aqueous compounds. Exemplary solvents for
both organic and aqueous compounds include, but are not limited to, methanol,
ethanol and/or tetrahydrofuran (THF). The mixture can be contacted, preferably
refluxed, under any atmosphere to form the desired ligand. Preferably, the mixture is
refluxed for at least 10, preferably 20 minutes, cooled and the desired ligand can be

30   recovered. Generally, after refluxing and cooling, the ligand can be recovered in a
crystalline form.

- 8 -

To prepare another specific diimine ligand wherein the R' group is anything other than hydrogen, a similar procedure can be used. For example, at least a two-fold molar excess of aniline or a substituted aniline can be combined with a compound capable of dissolving both organic and aqueous compounds and a very

5   minor amount of formic acid. Then, about a one molar equivalent of an alpha-diketone (R'COCOR') can be added to the mixture. The mixture can be stirred, under atmospheric conditions of temperature and pressure until the reaction is complete and the desired ligand is formed. Preferably, water is absent from the reaction mixture. Generally, the reaction will be complete in about 18, preferably 24

10   hours. A crystalline ligand product can be recovered according to any method known in the art.

The nickel bis(β-diketonate), nickel bis(β-ketoester), nickel β-diketonate halide and nickel β-ketoester halide can be prepared by any method known in the art. Typical syntheses of such nickel complexes can be found in Bullen, G.J.,

15   Mason, R., and Pauling, P., Inorganic Chemistry, Vol. 4, pp. 456-462 (1965), herein incorporated by reference. Alternatively, and especially in the case of nickel β-diketonate halides and nickel β-ketoester halides, the salt of the β-diketone or β-ketoester can be prepared then reacted with the correct quantity of nickel halide. A mixture of an appropriate Brönsted base, such as but not limited to sodium or

20   potassium hydride or sodium or potassium methoxide, is mixed with a solvent capable of dissolving or becoming miscible with the β-diketone or β-ketoester. Exemplary solvents include toluene, benzene, methanol, or ethanol. One molar equivalent of the β-diketone or β-ketoester is added slowly to this mixture. Reaction is known to occur as evidenced by the evolution of heat and a change in the physical

25   appearance of the mixture. Once all reactants have contacted, reaction times from 4 to 12 hours are sufficient to ensure complete reaction. If the product salt of the β-diketone or β-ketoester is not soluble in the solvent chosen, the solvent is removed by filtration or vacuum and the salt dissolved in a solvent in which it is soluble. Exemplary solvents include methanol and ethanol. This solution is then added to a

30   one half molar equivalent of nickel halide that has been suspended or dissolved in the same solvent or a solvent with which the first solvent is miscible. The preceding reactant ratio results in the formation of the nickel bis(β-diketonate) or nickel bis(β-

ketoester). If the nickel β-diketonate halide or nickel β-ketoester halide are desired, the solution is added to one molar equivalent of nickel halide as described. Reaction is known to occur as evidenced by the formation of a soluble green species. Reaction times of 4 to 12 hours are sufficient to ensure complete reaction. The byproduct

5   sodium or potassium halide salt is then removed from the reaction product by filtration and/or centrifugation. The solvent is removed by vacuum to yield the nickel complex used in the nickel diimine complex synthesis.

After formation of a diimine nickel complex, the diimine nickel complex can be recovered by any method known in the art, such as, for example

10 evaporation and/or vacuum filtration of the solvent. Further, if desired, the diimine nickel complex can be further purified by washing. One exemplary wash compound can be heptane. The diimine nickel complex catalyst system can be recovered and used as a solid, heterogeneous catalyst system.

Reactants, Polymerization and Polymer Products

15   Polymers produced according to the process of this invention can be homopolymers of mono-1-olefins or copolymers of at least two different mono-1-olefins. Exemplary mono-1-olefins useful in the practice of this invention include, but are not limited to mono-1-olefins having from about 2 to about 10 carbon atoms per molecule. Preferred mono-1-olefins include, but are not limited to ethylene,

20 propylene, 1-butene, 1-pentene, 1-hexene, 1-heptene, 3-methyl-1-butene, 4-methyl-1-pentene, 1-octene, 1-nonene and 1-decene. If the reaction product is a copolymer, one mono-1-olefin monomer can be polymerized with a mono-1-olefin comonomer which is a different alpha-olefin, usually having from about 3 to about 10, preferably from 3 to 8 carbon atoms per molecule. Exemplary comonomers include, but are not

25 limited to, propylene, 1-butene, butadiene, 1-pentene, 1-hexene, 1-octene, 4-methyl-1-pentene, and mixtures thereof. Preferably, if the monomer is ethylene, the comonomer is 1-hexene and/or 4-methyl-1-pentene, in order to achieve maximum polymer product toughness. Preferably, if the monomer is propylene, the comonomer is ethylene and/or butadiene in order to achieve maximum polymer product toughness

30 and clarity.

If a comonomer is used, the comonomer can be added to the polymerization reactor, or reaction zone, in an amount within a range of about 1 to

about 20 weight percent, preferably within 7 to about 18 weight percent, based on the weight of the ethylene monomer. Most preferably, a comonomer is present in the reaction zone within a range of about 10 to about 16 weight percent, in order to produce a polymer having the most desired physical properties.

5   Polymerization of the monomer and optional comonomer must be carried out under slurry, also known as loop/slurry or particle form, polymerization conditions wherein the temperature is kept below the temperature at which polymer swells significantly. Slurry polymerization processes are much easier to operate and maintain than other polymerization processes; a polymer product produced by a slurry

10   process can be recovered much more easily. Such polymerization techniques are well-known in the art and are disclosed, for instance, in Norwood, U.S. Pat. No. 3,248,179, the disclosure of which is hereby incorporated by reference.

The slurry process generally is carried out in an inert diluent (medium), such as, for example, a paraffin, cycloparaffin, and/or aromatic hydro-

15   carbon. Preferably, the inert diluent is an alkane having less that about 12 carbon atoms per molecule, for best reactor operation and polymer product. Exemplary diluents include, but are not limited to propane, n-butane, isobutane, n-pentane, 2-methylbutane (isopentane), and mixtures thereof. Isobutane is the most preferred diluent due to low cost and ease of use.

20   The temperature of the polymerization reactor, or reaction zone, when using isobutane as the reactor diluent, according to this invention, is critical and must be kept within a range of about 5° to about 100°C (41° - 212°F) and preferably within a range of about 10° to about 70°C (50° - 158°F). Most preferably, the reaction zone temperature is within a range of 20° to 60°C (68° - 140°F) for best

25   catalyst activity and productivity. Reaction temperatures below about 10°C can be ineffective for polymerization.

Pressures in the slurry process can vary from about 100 to about 1000 psia (0.76 - 7.6 MPa), preferably from about 200 to about 700 psia. Most preferably, the reaction zone is maintained at a pressure within a range of 300 to 600 psia for

30   best reactor operating parameters and best resultant polymer product. The catalyst system is kept in suspension and is contacted with the monomer and comonomer(s) at sufficient pressure to maintain the medium and at least a portion of the monomer and

- 11 -

comonomer(s) in the liquid phase. The medium and temperature are thus selected such that the polymer or copolymer is produced as solid particles and is recovered in that form. Catalyst system concentrations in the reactor can be such that the catalyst system content ranges from 0.001 to about 1 weight percent based on the weight of

5 the reactor contents.

The catalyst system and methylaluminoxane (MAO) can be added to the reactor in any order to effect polymerization. For example, catalyst system can be added, then some reactor diluent, such as isobutane, followed by MAO, then more diluent and finally, monomer and optional comonomer. However, as stated earlier,

10 this addition order can be varied, depending on equipment availability and/or desired polymer product properties. Preferably, the catalyst system and MAO are not pre-contacted prior to addition to the polymerization reactor due to a possible decrease in catalyst activity.

The amount of catalyst system and MAO added to the reactor can

15 vary. Generally, a molar excess of MAO is present, relative to the diimine nickel complex. Preferably, the aluminum to nickel (Al:Ni) molar ratio is less than about 1500:1, more preferably within a range of about 50:1 to about 600:1. Most preferably, the molar ratio of aluminum to nickel is within a ratio of 100:1 to 400:1 for best catalyst system activity and productivity.

20 Two preferred polymerization methods for the slurry process are those employing a loop reactor of the type disclosed in Norwood and those utilizing a plurality of stirred reactors either in series, parallel or combinations thereof wherein the reaction conditions can be the same or different in the different reactors. For instance, in a series of reactors, a chromium catalyst system which has not been

25 subjected to the reduction step can be utilized either before or after the reactor utilizing the catalyst system of this invention.

Polymers produced in accordance with this invention generally have a relatively narrow heterogeneity index (HI), which is a ratio of the weight average molecular weight (M_w) and the number average molecular weight (M_n) (also

30 expressed as M_w/M_n). Polymers produced in accordance with this invention usually have a HI within a range of about 3 to about 10, preferably within a range of about 3 to about 6, for best indication of processability.

- 12 -

Polymers produced in accordance with this invention are very unique because of a significant amount of short chain branching which can be produced even in the absence of a comonomer added to the reactor. This short chain branching is evidence that some sort of comonomers are produced in-situ in the reactor and are

5   incorporated into the polymer and/or that the catalyst can form short chain branches by rearrangement of the main polymer chain through successive hydride elimination, olefin rotation, and hydride re-addition reactions. This series of steps may not involve discrete intermediates and may rather be a concerted or continuous series of reactions with no distinct intermediates formed. Such rearrangements can be termed

10 "chain walking". Chain walking can be described by the active metal catalyst, i.e. nickel, "walking" a distance along the polymer backbone during polymerization and hence, the short chain branch length can be dictated by the rate of ethylene insertion relative to the combined rates of hydride elimination, olefin rotation, and hydride re-addition. Usually polymers produced in accordance with this invention, wherein no

15 comonomer is added to the polymerization reactor comprise up to about 3000, and generally from about 20 to about 3000 short chain branches per 10,000 (or from about 2 to about 300 short chain branches per 1000) backbone carbon atoms of the polymer. Furthermore, the short chain branches produced comprise both odd and even carbon branches, i.e., branches comprising an odd number of carbon atoms per

20 short chain branch, as well as branches comprising an even number of carbon atoms per short chain branch.

If desired, optional addition of one or more comonomers can be added to the polymerization reactor. The affirmatively added comonomers can further increase the amount of short chain branching in the resultant polymer, or copolymer.

25 Polymers produced with the addition of a comonomer can have a greater number of short chain branches in addition to those generated as described above. If a comonomer is affirmatively added to the polymerization reactor, these polymers usually can comprise up to about 3500, and generally from about 20 to about 3500, short chain branches per 10,000 backbone carbon atoms of polymer.

30 A further understanding of the invention and its advantages is provided by the following examples.

- 13 -

EXAMPLES

The following Examples illustrate various aspects of the invention. Data are included for each example about polymerization conditions, as well as the resultant polymer. All chemical handling, including reactions, preparation and storage, was performed under a dry, inert atmosphere (usually nitrogen). Unless otherwise indicated, bench scale polymerizations were completed in a 2.6 liter auto-clave reactor at the desired temperature using an isobutane (1.2 liter) slurry. The reactor was heated to 120°C and purged with nitrogen for about 20 minutes. The reactor then was cooled to the desired polymerization temperature and pressurized with isobutane to about 400 psig. A known quantity (mass) of diimine nickel complex catalyst was charged to the reactor against a countercurrent of isobutane and the agitator was set at 490 rpm. If hydrogen was charged to the reactor, hydrogen addition was followed by isobutane. The desired quantity of methylaluminoxane (MAO) (10 weight % in toluene) was charged directly to the reactor via syringe. After the full volume of isobutane was added, ethylene was added to bring the total reactor pressure to 550 psig. Ethylene was fed on demand and the polymerization reaction terminated when ethylene flow into the reactor ceased. Run times for each polymerization reaction are provided in the Tables.

The abbreviations for the catalyst systems used are as follows:

$[(iPr_2Ph)_2DABMe_2]Ni(acac)_2$ -
N,N'-bis(2,6-diisopropylphenyl)-2,3-butanediimine nickel(II) bis(acetylacetonate)

$[(iPr_2Ph)_2DABMe_2]Ni(hfacac)_2$ -
N,N'-bis(2,6-diisopropylphenyl)-2,3-butanediimine nickel(II) bis(1,1,1,5,5,5-hexafluoroacetylacetonate)

$[(iPr_2Ph)_2DABMe_2]Ni(hfacac)Cl$ -
N,N'-bis(2,6-diisopropylphenyl)-2,3-butanediimine nickel(II) (1,1,1,5,5,5-hexafluoroacetylacetonate)chloride

$[(iPr_2Ph)_2DABMe_2]Ni(allOacac)_2$ -
N,N'-bis(2,6-diisopropylphenyl)-2,3-butanediimine bis(allylacetylacetonato) nickel(II)

$[(iPr_2Ph)_2DABMe_2]Ni(Phacac)_2$ -
N,N'-bis(2,6-diisopropylphenyl)-2,3-butanediimine nickel(II) bis(benzoylacetonate)

$[(iPr_2Ph)_2DABMe_2]Ni(PhCF_3acac)_2$ -

- 14 -

N,N'-bis(2,6-diisopropylphenyl)-2,3-butanediimine nickel(II) bis(benzoyl-1,1,1-trifluoroacetonate)

[(iPr₂Ph)₂DABMe₂]Ni(CF₃acac)₂ -

N,N'-bis(2,6-diisopropylphenyl)-2,3-butanediimine nickel(II) bis(1,1,1-
5   trifluoroacetylacetonate)

[(iPr₂Ph)₂DABMe₂]Ni(CClF₂acac)₂ -

N,N'-bis(2,6-diisopropylphenyl)-2,3-butanediimine nickel(II) bis(1-chloro-1,1-
difluoroacetylacetonate)

[(iPr₂Ph)₂DABMe₂]Ni(CF₃MeOacac)₂ -

10   N,N'-bis(2,6-diisopropylphenyl)-2,3-butanediimine bis(methyltrifluoroacetoacetonato)
nickel(II)

[(iPr₂Ph)₂DABMe₂]Ni(CF₃tBuacac)₂ -

N,N'-bis(2,6-diisopropylphenyl)-2,3-butanediimine nickel(II) bis(1,1,1-trifluoro-5,5-
dimethylacetylacetonate)

15   [(iPr₂Ph)₂DABMe₂]Ni(CF₃OEt-α-Meacac)₂ -

N,N'-bis(2,6-diisopropylphenyl)-2,3-butanediimine bis(ethyl α-methyl-4,4,4-
trifluoroacetoacetato) nickel(II)

[(iPr₂Ph)₂DABMe₂]Ni(CF₃furacac)₂ -

N,N'-bis(2,6-diisopropylphenyl)-2,3-butanediimine nickel(II) bis(4,4,4-trifluoro-1-(2-
20   furyl)acetylacetonate)

[(iPr₂Ph)₂DABMe₂]Ni(CF₃CF₂CF₂tBuacac)₂ -
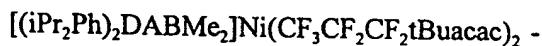
N,N'-bis(2,6-diisopropylphenyl)-2,3-butanediimine nickel(II) bis(2,2-dimethyl
6,6,7,7,8,8,8-heptafluoro-3,5-octanedionate)

[(iPr₂Ph)₂DABAn]Ni(hfacac)₂ -

25   N,N'-bis(2,6-diisopropylphenyl)acenaphthyl nickel(II) bis(hexafluoroacetylacetonate)

[(Me₂Ph)₂DABH₂]Ni(acac)₂ -

N,N'-bis(2,6-dimethylphenyl)-2,3-ethylenediimine nickel(II) bis(acetylacetonate)

[(Me₂Ph)₂DABMe₂]Ni(acac)₂ -

N,N'-bis(2,6-dimethylphenyl)-2,3-butanediimine nickel(II) bis(acetylacetonate).

30   In general, catalyst systems used for polymerization in the Examples
were prepared as described in this application.

- 15 -

Mass Catalyst (grams) is the mass of catalyst system charged to the polymerization reactor for each Run. Polymer density was determined in grams per cubic centimeter (g/cc) on a compression molded sample, cooled at about 15°C per hour, and conditioned for about 40 hours at room temperature in accordance with

5   ASTM D1505 and ASTM D1928, procedure C. High load melt index (HLMI, g/10 mins) was determined in accordance with ASTM D1238 at 190°C with a 21,600 gram weight. Melt index (MI, g/10 mins) was determined in accordance with ASTM D1238 at 190°C with a 2,160 gram weight. Size exclusion chromatography (SEC) analyses were performed at 140°C on a Waters, model 150 GPC with a refractive

10   index detector. A solution concentration of 0.17 to 0.65 weight percent in 1,2,4-trichlorobenzene was found to give reasonable elution times. Reported weight average molecular weight (M_w) and number average molecular weight (M_n) values (results) need to be multiplied by a factor of 1000 for the actual value. Reported Al:Ni ratio values are expressed as molar ratio values. Values that were not

15   determined are represented as "ND" in the Tables.

EXAMPLE 1

This example shows that high catalyst system productivity can be achieved by substituting one or both of the halide ligands of a diimine nickel dihalide complex with a β-diketonate or β-ketoester ligand.

20   Polymerizations in the following Runs were carried out as described above, with a reactor pressure of 550 psig ethylene in isobutane slurry at 40°C. MAO was added in a 10% wt/wt solution in toluene. Polymerization results are listed below in Table 1.

TABLE 1

Run #	Catalyst	Mass cat. (g)	Run Time (mins.)	Productivity (g PE/g Ni)	MI	HLMI	Density (g/cc)	Al:Ni
101	[(iPr$_2$Ph$_2$)DABMe$_2$]NiBr$_2$	0.0218	13	490	ND	ND	ND	240
102	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(CF$_3$CF$_2$CF$_2$tBuacac)$_2$	0.0583	4	7310	0	0	0.9196	150
103	[(iPr$_2$Ph$_2$)DABMe$_2$]NiCl$_2$	0.0200	9	11400	0	0	0.9099	230
104	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0050	4	12000	ND	ND	ND	1200
105	[(iPr$_2$Ph$_2$)DABMe$_2$]NiCl$_2$	0.0230	30	13400	0	0	0.9081	200
106	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(CF$_3$OEt-α-Meacac)$_2$	0.0163	21	13900	0	0	0.9074	450
107	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(Phacac)$_2$	0.0109	18	17100	ND	ND	0.9212	610
108	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(allOacac)$_2$	0.0209	27	21300	0	0	0.9157	300
109	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(CF$_3$acac)$_2$	0.0020	8	29500	0	0	ND	3300
110	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(CF$_3$furacac)$_2$	0.0121	17	30700	0	0	0.8961	610
111	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(PhCF$_3$acac)$_2$	0.0165	41	33700	0	0	0.9137	460
112	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0111	3	35000	0	0	0.8819	670
113	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(CClF$_2$acac)$_2$	0.0118	10	96200	0	0	0.8857	580
114	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0195	15	108000	0	0	0.8926	ND
115	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(tBuCF$_3$acac)$_2$	0.0114	17	139000	ND	ND	0.8918	640
116	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(CF$_3$acac)$_2$	0.0041	60	157000	0	0	0.8955	1600
117	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0092	18	174000	0	0	0.8888	810

Run #	Catalyst	Mass cat. (g)	Run Time (mins.)	Productivity (g PE/g Ni)	MI	HLMI	Density (g/cc)	Al:Ni
118	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)Cl	0.0062	27	198000	0	0	0.8871	1000
119	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0052	31	293000	0	0	0.9100	860
120	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0100	31	327000	0	0	0.9087	750
121	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0025	14	378000	0	0	0.9017	600
122	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0040	35	493000	0	0	0.9111	750
123	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0052	31	621000	0	0	0.8853	1400

- 18 -

The data in Table 1 show that diimine nickel(II) catalyst systems containing β-diketonate or β-ketoester ligands can effectively polymerize ethylene with higher productivity than catalysts containing exclusively diimine and halide ligands (see Runs 101, 103 and 105). The data also show that the addition of a

5 single β-diketonate ligand affords much higher productivity. Also note that reactor temperatures are within commercially acceptable ranges, i.e., between 40 and 80°C.

EXAMPLE 2

This example shows that process conditions can be changed without losing the high productivity attained by one or both of the halide ligands of a diimine

10 nickel dihalide complex with a β-diketonate or β-ketoester ligand. Again, all of the following polymerizations were carried out as described above, with a reactor pressure of 550 psig ethylene in isobutane slurry. MAO was added in a 10% wt/wt solution in toluene. Process conditions were varied by changing the polymerization temperature and, as a result, the quantity of dissolved ethylene in the reaction

15 medium. The structure of the diimine ligand was also varied. Polymerization catalyst systems and results are listed below at temperatures of 27, 60, and 80 °C in Tables 2, 3, and 4, respectively.

TABLE 2   (all Runs were at 27°C)

Run #	Catalyst	Mass cat. (g)	Run Time (mins)	Productivity (g PE/g Ni)	MI	HLMI	Density (g/cc)	Al:Ni	Mn	Mw	HI
201	[(iPr$_2$Ph$_2$)DABMe$_2$]NiBr$_2$	0.0340	15	940	ND	ND	0.9450	160	ND	ND	ND
202	[(iPr$_2$Ph$_2$)DABAn]NiBr$_2$	0.0303	25	1210	ND	ND	0.9564	200	ND	ND	ND
203	[(iPr$_2$Ph$_2$)DABMe$_2$]NiCl$_2$	0.0231	24	1580	ND	ND	ND	200	ND	ND	ND
204	[(Me$_2$Ph$_2$)DABMe$_2$]NiBr$_2$	0.0301	17	2020	0	0.05	0.9496	140	239	531	2.22
205	[(Me$_2$Ph$_2$)DABH$_2$]NiBr$_2$	0.0294	24	2510	1.4	84	0.9749	140	20	74	3.64
206	[(iPr$_2$Ph$_2$)DABAn]NiCl$_2$	0.0343	31	4080	0	0	0.9421	160	399	1059	2.65
207	[(Me$_2$Ph$_2$)DABH$_2$]NiCl$_2$	0.0233	31	4950	0.46	38	0.9691	140	ND	ND	ND
208	[(iPr$_2$Ph$_2$)DABMe$_2$]NiCl$_2$	0.0176	41	26900	0	0	0.9175	260	ND	ND	ND
209	[(Me$_2$Ph$_2$)DABMe$_2$]NiCl$_2$	0.0413	60	27900	0	0.07	0.9457	87	95	373	3.92
210	[(Me$_2$Ph$_2$)DABH$_2$]Ni(acac)$_2$	0.0362	30	29000	0	0.45	0.9305	120	ND	ND	ND
211	[(Me$_2$Ph$_2$)DABH$_2$]Ni(acac)$_2$	0.0021	9	42300	0	0.07	0.9383	420	ND	ND	ND
212	[(iPr$_2$Ph$_2$)DABMe$_2$]NiCl$_2$	0.0309	74	57700	0	0	0.9132	150	1038	2638	2.54
213	[(Me$_2$Ph$_2$)DABH$_2$]Ni(acac)$_2$	0.0139	14	78000	0	0.15	0.9180	320	ND	ND	ND
214	[(Me$_2$Ph$_2$)DABMe$_2$]Ni(acac)$_2$	0.0147	18	78800	0	0.33	0.9331	320	ND	ND	ND
215	[(Me$_2$Ph$_2$)DABMe$_2$]Ni(acac)$_2$	0.0090	14	82100	ND	ND	ND	520	ND	ND	ND
216	[(iPr$_2$Ph$_2$)DABAn]Ni(hfacac)$_2$	0.0142	25	96900	0	0	0.9205	580	420	1425	3.4

Run #	Catalyst	Mass cat. (g)	Run Time (mins)	Productivity (g PE/g Ni)	MI	HLMI	Density (g/cc)	Al:Ni	Mn	Mw	HI
217	[(Me$_2$Ph$_2$)DABH$_2$]Ni(hfacac)$_2$	0.0100	9	138000	5.6	215	0.9450	630	ND	ND	ND
218	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0204	30	149000	0	0	0.8951	370	516	1687	3.27
219	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)Cl	0.0134	35	199000	0	0	0.9002	450	360	1523	4.23

TABLE 3 (all Runs were at 60°C)

Run #	Catalyst	Mass cat. (g)	Run Time (mins)	Productivity (g PE/g Ni)	MI	HLMI	Density (g/cc)	Al:Ni	Mn	Mw	HI
301	[(Me$_2$Ph$_2$)DABH$_2$]Ni(acac)$_2$	0.0161	6	1580	ND	ND	ND	280	ND	ND	ND
302	[(Me$_2$Ph$_2$)DABH$_2$]NiCl$_2$	0.0229	1	3810	1.7	112	0.9618	150	17	84	4.91
303	[(Me$_2$Ph$_2$)DABMe$_2$]NiCl$_2$	0.0545	16	4710	0.21	22	0.9056	26	33	94	2.82
304	[(Me$_2$Ph$_2$)DABH$_2$]NiCl$_2$	0.0274	8	5130	2.5	126	0.9546	73	16	73	4.46
305	[(Me$_2$Ph$_2$)DABH$_2$]NiCl$_2$	0.0233	8	5470	2.6	127	0.9530	58	ND	ND	ND
306	[(iPr$_2$Ph$_2$)DABAn]NiBr$_2$	0.0483	22	8660	0	0.11	0.8963	130	143	550	3.86
307	[(iPr$_2$Ph$_2$)DABAn]NiCl$_2$	0.0283	11	8740	0	0	0.8957	190	220	808	3.68
308	[(iPr$_2$Ph$_2$)DABMe$_2$]NiBr$_2$	0.0188	15	10200	0	0	0.8753	280	632	1725	2.73
309	[(Me$_2$Ph$_2$)DABMe$_2$]NiBr$_2$	0.0283	11	10400	0.26	16	0.9095	150	38	110	2.92
310	[(Me$_2$Ph$_2$)DABH$_2$]Ni(acac)$_2$	0.0085	6	10600	ND	ND	ND	520	ND	ND	ND
311	[(Me$_2$Ph$_2$)DABH$_2$]NiBr$_2$	0.0312	9	12600	4.4	169	0.9527	130	15	86	5.93
312	[(Me$_2$Ph$_2$)DABMe$_2$]NiCl$_2$	0.0328	5	13100	0.03	5.5	0.9107	110	53	164	3.10
313	[(Me$_2$Ph$_2$)DABMe$_2$]Ni(acac)$_2$	0.0313	7	17000	ND	ND	ND	150	ND	ND	ND
314	[(iPr$_2$Ph$_2$)DABMe$_2$]NiCl$_2$	0.0202	7	17100	0	0	0.8817	220	390	1228	3.15
315	[(Me$_2$Ph$_2$)DABMe$_2$]Ni(acac)$_2$	0.0158	5	18400	0.02	3.0	0.9215	300	ND	ND	ND
316	[(iPr$_2$Ph$_2$)DABMe$_2$]NiCl$_2$	0.0185	17	52100	0	0	0.8805	250	ND	ND	ND

Run #	Catalyst	Mass cat. (g)	Run Time (mins)	Productivity (g PE/g Ni)	MI	HLMI	Density (g/cc)	Al:Ni	Mn	Mw	HI
317	[(iPr$_2$Ph$_2$)DABAn]Ni(hfacac)$_2$	0.0048	16	104000	0	0.08	0.9011	1700	309	1366	4.4
318	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0088	19	116000	0	0	0.8867	680	ND	ND	ND
319	[(Me$_2$Ph$_2$)DABH$_2$]Ni(hfacac)$_2$	0.0034	4	137000	1.3	78	0.9569	1850	ND	ND	ND
320	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0029	14	302000	0	0	0.8986	2600	788	2389	3.0

- 23 -

TABLE 4 (all Runs were at 80°C)

Run #	Catalyst	Mass cat. (g)	Run Time (mins)	Productivity (g PE/g Ni)	MI	HLMI	Density (g/cc)	Al:Ni	Mn	Mw	HI
401	[(iPr₂Ph₂)DABAn]NiCl₂	0.0326	9	1980	ND	ND	0.9048	160	ND	ND	ND
402	[(Me₂Ph₂)DABH₂]Ni(acac)₂	0.0161	3	3860	0.46	24	0.9246	280	ND	ND	ND
403	[(iPr₂Ph₂)DABAn]NiBr₂	0.0239	5	4580	0	1.5	0.8644	260	ND	ND	ND
404	[(Me₂Ph₂)DABH₂]NiBr₂	0.0318	6	5160	16	ND	0.9466	130	12	44	3.62
405	[(Me₂Ph₂)DABMe₂]Ni(acac)₂	0.0253	3	6650	1.5	67	0.9118	180	ND	ND	ND
406	[(iPr₂Ph₂)DABMe₂]NiBr₂	0.0363	5	6740	0	0	0.8680	150	255	652	2.56
407	[(Me₂Ph₂)DABMe₂]Ni(acac)₂	0.0131	4	7140	ND	ND	ND	360	ND	ND	ND
408	[(Me₂Ph₂)DABMe₂]NiBr₂	0.0263	9	9920	72	ND	ND	160	14	31	2.22
409	[(Me₂Ph₂)DABH₂]Ni(hfacac)₂	0.0035	2	10800	ND	ND	0.9997	1800	ND	ND	ND
410	[(iPr₂Ph₂)DABAn]Ni(hfacac)₂	0.0202	4	24600	0	0.12	0.8899	410	145	644	4.4
411	[(iPr₂Ph₂)DABMe₂]Ni(hfacac)Cl	0.0088	4	25700	0	0.04	0.8867	680	ND	ND	ND
412	[(iPr₂Ph₂)DABMe₂]Ni(hfacac)₂	0.0059	4	83600	0	0	0.8912	1300	394	1713	4.3

- 24 -

The results in Tables 2,3, and 4 show that the high productivity seen with nickel diimine complexes containing one or two β-dikctonate or β-ketoester ligands is maintained when temperature (and therefore dissolved ethylene concentration as well) and the diimine ligand are changed. Again, note that reactor temperatures were within commercially acceptable ranges, i.e., between 40 and 80°C.

EXAMPLE 3

This example shows that the high productivity seen with diimine nickel complexes containing one or two β-ketoester ligands is maintained at low Al:Ni ratios; i.e., low levels of MAO. Again, all of the following polymerizations were carried out as described above, with a reactor pressure of 550 psig ethylene in isobutane slurry. MAO was added in a 10% wt/wt solution in toluene. Catalyst system used in Runs 523-527 were physically mixed with an inert, filler material before addition to the reactor in order to expedite weighing small amounts of catalyst system. Then, the actual mass of catalyst system added to the reactor was calculated, based on the weight ratio of filler and catalyst system combined.

TABLE 5

Run #	Catalyst	Mass cat. (g)	T (°C)	Run Time (mins)	Productivity (g PE/g Ni)	MI	HLMI	Density (g/cc)	Al:Ni
501	[(Me$_2$Ph$_2$)DABH$_2$]Ni(acac)$_2$	0.0110	13	9	87200	0	0.19	0.9348	160
502	[(Me$_2$Ph$_2$)DABH$_2$]Ni(acac)$_2$	0.0362	27	11	29000	0	0.45	0.9305	120
503	[(Me$_2$Ph$_2$)DABMe$_2$]Ni(acac)$_2$	0.0147	27	17	78800	0	0.33	0.9331	320
504	[(Me$_2$Ph$_2$)DABH$_2$]Ni(acac)$_2$	0.0139	27	10	78000	0	0.15	0.9180	320
505	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0204	27	30	149000	0	0	0.8951	370
506	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)Cl	0.0134	27	35	199000	0	0	0.9002	450
507	[(Me$_2$Ph$_2$)DABMe$_2$]Ni(acac)$_2$	0.0090	27	14	82100	ND	ND	ND	520
508	[(Me$_2$Ph$_2$)DABH$_2$]Ni(acac)$_2$	0.0448	40	7	28500	0	0.34	0.9221	100
509	[(Me$_2$Ph$_2$)DABH$_2$]Ni(hfacac)$_2$	0.0050	40	5	52700	1.5	51	0.9608	250
510	[(Me$_2$Ph$_2$)DABMe$_2$]Ni(acac)$_2$	0.0185	40	10	51800	0	0.12	0.9360	250
511	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(allOacac)$_2$	0.0209	40	27	21300	0	0	0.9157	300
512	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(PhCF$_3$acac)$_2$	0.0165	40	41	33700	0	0	0.9137	460
513	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(CF$_3$CF$_2$CF$_2$tBuacac)$_2$	0.0608	60	7	4430	0	0	<0.8800	150
514	[(Me$_2$Ph$_2$)DABMe$_2$]Ni(acac)$_2$	0.0313	60	7	17000	ND	ND	ND	150
515	[(Me$_2$Ph$_2$)DABMe$_2$]Ni(acac)$_2$	0.0158	60	5	18400	0.02	3.0	0.9215	300
516	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(allOacac)$_2$	0.0177	60	4	6450	0	0	0.9060	360
517	[(Me$_2$Ph$_2$)DABMe$_2$]Ni(acac)$_2$	0.0253	80	3	6650	1.5	67	0.9118	180

Run #	Catalyst	Mass cat. (g)	T (°C)	Run Time (mins)	Productivity (g PE/g Ni)	MI	HLMI	Density (g/cc)	Al:Ni
518	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(CF$_3$furacac)$_2$	0.0310	80	6	8600	0	0.08	0.8836	240
519	[(Me$_2$Ph$_2$)DABH$_2$]Ni(acac)$_2$	0.0161	80	3	3900	0.46	24	0.9246	280
520	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(PhCF$_3$acac)$_2$	0.0216	80	4	12000	0	0.04	0.9013	350
521	[(Me$_2$Ph$_2$)DABMe$_2$]Ni(acac)$_2$	0.0131	80	4	7140	ND	ND	ND	360
522	[(iPr$_2$Ph$_2$)DABAn]Ni(hfacac)$_2$	0.0202	80	4	24600	0	0.12	0.8899	410
523	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0038	40	16	116000	ND	ND	ND	1590
524	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0054	40	10	53000	ND	ND	ND	830
525	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0046	40	20	169000	ND	ND	ND	660
526	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0044	40	47	104000	ND	ND	ND	340
527	[(iPr$_2$Ph$_2$)DABMe$_2$]Ni(hfacac)$_2$	0.0052	40	28	99000	ND	ND	ND	140

The data in Table 5 show that high productivity can be achieved with diimine nickel complexes containing one or two β-diketonate or β-ketoester groups with low levels of MAO. Runs 523-527 clearly demonstrate that very high productivities can be achieved even at very low Al:Ni molar ratios, i.e., low amounts of MAO added to the polymerization reaction.

EXAMPLE 4

This Example shows that inventive catalyst systems can be used to produce syndiotactic polymers. The term "syndiotactic polymer", as used herein, includes those polymers having segments of more than 10 monomeric units in which the alkyl groups of each successive monomeric unit is on the opposite side of the plane of the polymer. Syndiotactic polymers produced according to the invention can have a wide range of applications based upon their physical properties. These syndiotactic polymers can be molded by heat to form shaped objects and they can be used to form fibers or filaments. These syndiotactic polymers also can be used for blending with polymers of different tacticity to vary the properties of such polymers.

In this example where information is given about the microstructure of polymers as determined by ^{13}CNMR, spectra were taken using standard accepted spectroscopy techniques. Polymer was dissolved in 1,2,4-trichlorobenzene and the spectra was taken with respect to an internal standard relative to hexamethylsiloxane which has a known reference point relative to tetramethylsilane; the base standard in the NMR spectra was 0 ppm based on tetramethylsilane. From the observed integrals of the relevant peaks, the details regarding the microstructure are calculated.

Meso Content = (mm) + ½ (mr)

Racemic Content = (rr) + ½ (mr)

Isotacticity = % (mm)

Heterotacticity = % (mr)

Syndiotacticity = % (rr)

$$\text{Randomness Index} = \frac{(mr)100}{2(m)(r)}$$

$$\text{Average Isotactic Block Length} = 1 + \frac{2(mm)}{(mr)}$$

$$\text{Average Syndiotactic Block Length} = 1 + \frac{2(rr)}{(mr)}$$

- 28 -

For more detail regarding the determination of these values, reference can be made to Chapter 3 of <u>Chain Structure and Conformation of Macromolecules</u> (Academic Press, 1982) by Frank A. Bovey.

Polymerization was carried out as described above. Reactor temperature was 80°C. 0.0140 g of N,N'-bis(2,6-diisopropylphenyl)-2,3-butanedi-imine nickel(II) bis(acetylacetonate), designated as [(iPr$_2$Ph)$_2$DABMe$_2$]Ni(acac)$_2$ the nickel catalyst system and 5 mls of MAO (10 weight % in toluene) were added to the reactor, followed by propylene. Propylene was fed on demand and the polymeri-zation reaction terminated when propylene flow into the reactor ceased. Hydrogen was not added to the reactor. After one hour of reaction time, isobutane was removed to yield 4.2 g of polymer. Productivity was 2660 g polypropylene/g Ni. Polymer characterization by ^{13}CNMR is as follows.
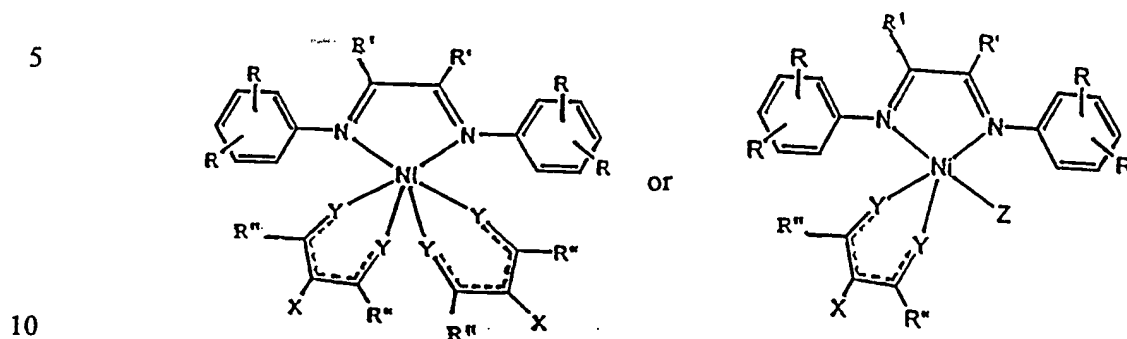
%[mm] = 6.00   %[m] = 17.1

%[mr] = 22.17   %[r] = 7.48

%[rr] = 71.83

The above data demonstrates that the inventive catalyst systems can produce syndiotactic polymers, such as syndiotactic polypropylene, as shown by approximately 72% rr triads as determined by ^{13}CNMR spectroscopy. While this invention has been described in detail for the purpose of illustration, it is not to be construed as limited thereby but is intended to cover all changes and modifications within the spirit and scope thereof.

<u>C L A I M S</u>

1.   A heterogeneous catalyst composition comprising:

a) a diimine nickel complex having a formula which is

or

wherein R can be the same or different and is a branched or linear alkyl or aromatic group having from about 1 to about 10 carbon atoms per alkyl group and can be in any position on the aromatic ring;

wherein R' can be the same or different and is hydrogen or a linear, branched, cyclic, bridging, aromatic, and/or aliphatic hydrocarbon having from about 1 to about 70 carbon atoms per radical group;

wherein R"CYCXCYR can be the same or different and is an α-deprotonated-β-diketone, an α-deprotonated-β-ketoester, a halogen or a mixture of any of two or more of said radicals, and wherein R and X can be the same or different and are individually hydrogen or a linear, branched, cyclic, bridging, aromatic or aliphatic hydrocarbon, or a mixture of any two or more of said radicals having from about 1 to about 70 carbon atoms per radical group.

wherein Y can be the same or different and is oxygen, sulfur, or selenium; and

wherein Z is a halogen which is fluorine, chlorine, bromine, or iodine;

and

b)   methylaluminoxane.

- 30 -

2.   A composition according to claim 1, wherein said diimine nickel complex and said methylaluminoxane are present in an amount so as to have an aluminum to nickel molar ratio of less than about 850:1.

3.   A composition according to claim 1, wherein said aluminum to nickel molar ratio in said catalyst system is within a range of about 50:1 to about 1200:1.

4.   A composition according to claim 3, wherein said aluminum to nickel molar ratio is within a range of about 50:1 to about 600:1.

5.   A composition according to claim 1, wherein said R substituent is a linear or branched aliphatic group having from about 1 to about 8 carbon atoms per group.

6.   A composition according to claim 5, wherein said R substituent is a linear or branched alkyl group having from about 1 to about 8 carbon atoms per group.

7.   A composition according to claim 6, wherein said R substituent is a methyl group, an isopropyl group, or a mixture thereof.

8.   A composition according to claim 1, wherein said R' substituent is hydrogen or a branched, linear, cyclic, aromatic or aliphatic hydrocarbon radical or a mixture of any two or more of said radicals having from about 1 to about 20 carbon atoms per radical.

9.   A composition according to claim 8, wherein said R' substituent is hydrogen or a branched, linear, cyclic, aromatic or aliphatic hydrocarbon radical having from about 1 to about 12 carbon atoms per radical.

10.   A composition according to claim 9, wherein said R' substituent is hydrogen, a methyl group, an ethyl group, a propyl group, a phenyl group, an acenaphthyl group, a cyclobutadienyl group or a mixture of any two or more of said groups.

11.   A composition according to claim 1, wherein R" and X are individually hydrogen or a hydrocarbon radical having from about 1 to about 10 carbon atoms per radical group.

12.   A composition according to claim 1, wherein one said R" and X are individually hydrogen or a linear, branched, cyclic, bridging, aromatic, or aliphatic hydrocarbon radical, or a mixture of any two or more of said radicals having from about 1 to about 70 carbon atoms per radical group, and wherein

5   another said R" is an alkoxide of a linear, a branched, a cyclic, a bridging, an aromatic, or an aliphatic hydrocarbon radical, or a mixture of any two or more of said radicals having from about 1 to about 70 carbon atoms per radical group.

13.   A composition according to claim 12, wherein one said R",

10   another said R" and X each have from about 1 to about 10 carbon atoms per radical group.

14.   A process according to claim 1, wherein said R"CYCXCYR" is 2,4-pentanedione, 1,1,1,5,5,5-hexafluoro-2,4-pentanedione, allylacetonacetate, benzoyl-acetonate, benzoyl-1,1,1-trifluoroacetone, 1,1,1-trifluoro-2,4-pentane-

15   dione, 1- chloro-1,1-difluoroacetylacetone methyl-4,4,4-trifluoroacetoacetate, 1, 1,1-trifluoro-5,5-dimethyl-2,4-pentanedione, ethyl alpha-methyl-4,4,4-trifluoro-acetoacetate, 4,4,4-trifluoro-1-(2-furyl)-1,3-butanedione, or 2,2-dimethyl-6, 6 , 7,7,8,8,8-heptafluoro-3,5-octanedione; and

Z is chloride or bromide.

20   15.   A process for polymerizing an olefin which comprises contacting in a reaction zone under slurry polymerization reactor conditions:

a) an olefin monomer; and

b) a heterogenous catalyst composition according to any one of the preceding claims.

25   16.   A process according to claim 15, wherein said slurry polymerization reactor conditions comprise a reaction temperature within a range of about 10° to about 90°C and a pressure within a range of about 100 to about 1000 psia.

17.   A process according to claim 15, wherein said slurry

30   polymerization is carried out in the presence of an isobutane diluent.

- 32 -

18.   A process according to claim 15, wherein the olefin monomer is ethylene.

19.   A process according to claim 18, which further comprises contacting a comonomer which is an alpha-olefin having from 3 to 10 carbon

5   atoms per molecule with (a) and (b).

20.   A process according to claim 19, wherein said comonomer is propylene, 1-butene, 1-pentene, 1-hexene, 1-octene, 4-methyl-1-pentene, or a mixture of any two or more of said comonomers.

21.   A process according to claim 20, wherein said comonomer is 1-

10   hexene, 4-methyl-1-pentene, or a mixture thereof.

22.   A process according to claim 15, wherein the olefin monomer is propylene.

23.   A process according to claim 22, which further comprises contacting a comonomer which is an alpha-olefin having from 2 to 10 carbon

15   atoms per molecule with (a) and (b).

24.   A process according to claim 22, which produces a polymer of syndiotactic polypropylene.

25.   A polymer composition of ethylene comprising from 20 to 3000 short chain branches per 10,000 backbone carbon atoms of said polymer; and

20   wherein said polymer has a heterogeneity index in the range of about 3 to about 8.

26.   A heterogeneous catalyst composition substantially as herein described with reference to any one of the Examples.

27.   A process for polymerizing an olefin according to claim 15,

25   substantially as herein described with reference to any one of the Examples.

28.   A polymer when produced by a process according to any one of claims 15-24 and 27.

29.   A polymer composition of ethylene substantially as herein described with reference to any one of Examples 1-3.

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) :Please See Extra Sheet.
US CL   : 502/117; 526/172, 348, 348.2, 348.4, 348.5
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
U.S. :   502/117; 526/172, 348, 348.2, 348.4, 348.5

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
 NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
 NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3,592,870 A (DUAN) 13 July 1971, whole document.	1-29
A	US 3,949,013 A (YOO et al) 06 April 1976, whole document.	1-29
A	US 5,852,145 A (MCLAIN et al) 22 December 1998, whole document.	1-29
X,P ——— Y,P	US 5,844,055 A (BRANDT et al) 01 December 1998, abstract, col. 8-9, table 3.	25 ——— 28, 29
X,E ——— Y,E	US 5,866,663 A (BROOKHART et al) 02 February 1999, col. 74, examples.	25 ——— 28, 29

☐ Further documents are listed in the continuation of Box C.	☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance		
"B"	earlier document published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)		
		"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 MARCH 1999	**15 APR 1999**
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer JAMES PASTERCZYK
Facsimile No. (703) 305-3230	Telephone No. (703) 308-0661

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/25889

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest   ☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet(1))(July 1992)∗

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER:
IPC (6):

B01J 31/00, 37/00; C08F 4/02, 4/60, 4/06, 210/00, 10/14, 110/14, 210/14

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING
This ISA found multiple inventions as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I, claim(s)1-24, 26 and 27, drawn to a two component catalyst composition and method of polymerizing olefins using the same.
Group II, claim(s) 25, 28 and 29, drawn to polyolefins.
The inventions listed as Groups I and II do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: the polymers of group II do not require the use of the special technical feature of the catalysts or method of polymerization of group I to make them. The polymers are conventional.

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